

Xenon Vessel Pumping Speed

DRAFT

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Tube gas conductance, molecular flow, from Practical Vacuum Techniques , Brunner & Batzer, 1974

$$Q_m := \frac{\pi d_{\text{tube}}^3}{12 l_{\text{tube}}} \cdot v_a \cdot (P_e - P_i) \quad \text{for dry air@20C, d, L in inches Q in (torr *L) /s equation is:}$$
$$Q_{\text{mol}} := \frac{80 \cdot d_{\text{tube}}^3}{l_{\text{tube}}} \cdot \Delta P_{\text{tube}}$$

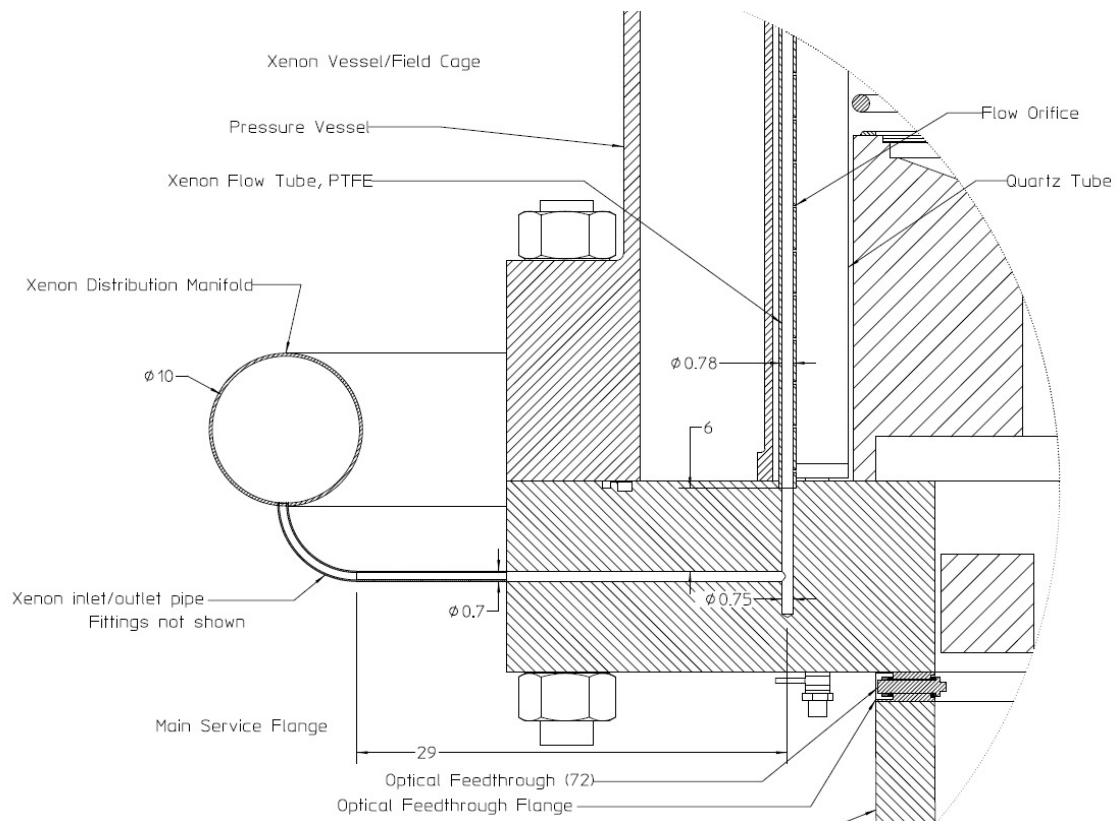
Since Mathcad does real units , let:

$$d_{\text{tube}} := 1 \text{ in} \quad l_{\text{tube}} := 1 \text{ in} \quad \Delta P_{\text{tube}} := 1 \text{ torr} \quad v_a := 124 \frac{\text{m}}{\text{s}}$$

then:

$$Q_m := \frac{v_a \cdot d_{\text{tube}}^3}{l_{\text{tube}}} \cdot \Delta P_{\text{tube}} \quad Q_m = 80 \frac{\text{torr} \cdot \text{L}}{\text{s}}$$

The scheme below distributes Xenon to and from the vessel through a set of 72 flow tubes. These are PTFE tubes located in the interstitial space behind the quartz tubes. The flow path from the Xenon vessel interior out to vacuum pumps is through a series of graded orifices in each tube (to equalize flow both top to bottom and transversely), through the tube, through an inlet tube, then to one of two large diameter manifolds (one inlet, one outlet), and finally out through several large diameter tubes which lead out of the water tank. A cross section detail is shown below:



Conductance path, from Xe interior to vacu pumps (assume 4, one one for each support leg):
number in parallel

Xe flow tube	$d_{ft} := .78\text{cm}$	$l_{ft} := 1.6\text{m}$	$n_{ft} := 72$
Xe inlet/outlet tube	$d_{tm} := 0.7\text{cm}$	$l_{tm} := 40\text{cm}$	$n_{fm} := 72$
manifold	$d_{man} := 10\text{cm}$	$l_{man} := 3\text{m}$	$n_{man} := 2$
manifold to pump(s)	$d_{mp} := 10\text{cm}$	$l_{mp} := 2.7\text{m}$	$n_{mp} := 4$

The flow holes are graded in size, in order to match flow rates through them from top to bottom. the lower holes must have a smaller diameter to match the conductance of the tube plus the largest hole at the top, further assume tube is open at top. Before we can go further with this design, we need to know the desired flow rate of Xe through the vessel. We will simplify here by assuming the tube "disappears" at the top and its effective conductance will be the conductance of a half height tube (effective tube height will likely be less). Conductances, for molecular flow are:

Flow tube	inlet/outlet tube	manifold	manifold to pump line
$C_{m_ft} := \frac{v_a \cdot d_{ft}^3}{0.5l_{ft}}$	$C_{m_tm} := \frac{v_a \cdot d_{tm}^3}{l_{tm}}$	$C_{m_man} := \frac{v_a \cdot d_{man}^3}{l_{man}}$	$C_{m_mp} := \frac{v_a \cdot d_{mp}^3}{l_{mp}}$
$C_{m_ft} = 0.1 \frac{\text{L}}{\text{s}}$	$C_{m_tm} = 0.1 \frac{\text{L}}{\text{s}}$	$C_{m_man} = 41.3 \frac{\text{L}}{\text{s}}$	$C_{m_mp} = 45.9 \frac{\text{L}}{\text{s}}$

Assume bends are negligible compared to length of tube, then total conductance is:

$$C_{m_tot} := \left[(n_{ft} \cdot C_{m_ft})^{-1} + (n_{fm} \cdot C_{m_tm})^{-1} + (n_{man} \cdot C_{m_man})^{-1} + (n_{mp} \cdot C_{m_mp})^{-1} \right]^{-1}$$

$$C_{m_tot} = 2.968 \frac{\text{L}}{\text{s}}$$

Most pumps have pumping speeds much higher than this, so this conductance will dominate and set the pumping speed. To find pressure in Xe vessel, we need to estimate outgassing rate for Xe vessel. Plexiglass outgassing rate, from chart: <http://www.ece.ualberta.ca/~schmaus/vacf/outgas.html>

$$q_{\text{PMMA}} := 10^{-6} \frac{\text{torr} \cdot \text{L}}{\text{s} \cdot \text{cm}^2} \quad \text{after full degassing}$$

Area of Xenon vessel

$$A_{\text{Xe}_v} := 2\pi r_{\text{Xe}}^2 + 2\pi r_{\text{Xe}} \cdot l_{\text{Xe}} \quad A_{\text{Xe}_v} = 5.932 \text{m}^2$$

Total outgass rate:

$$Q_{\text{Xe}_v} := q_{\text{PMMA}} \cdot A_{\text{Xe}_v} \quad Q_{\text{Xe}_v} = 0.059 \frac{\text{torr} \cdot \text{L}}{\text{s}}$$

Equilibrium pressure in Xe vessel

$$P_{Xe_v} := 10^{-6} \text{ torr} + \frac{Q_{Xe_v}}{C_{m_tot}} \quad P_{Xe_v} = 0.02 \text{ torr} \quad \text{this may actually be in viscous flow mode}$$

Xenon diffusion through Acrylic Xenon vessel

From Xenon Self-Diffusion in organic polymers by Pulsed Field Gradient NMR Spectroscopy, Junker & Veeman 1998, self-diffusion coefficient for polypropylene (assume similar to acrylic) is:

$$D_{Xe_PP} := 4 \cdot 10^{-12} \frac{\text{m}^2}{\text{s}} \quad (\text{assume at room temp, not stated in ref})$$

Xe concentration in Xe vessel

$$C_i := \frac{1}{v} \quad v := \frac{RT}{P} \quad C_i := \frac{P_{MOPa}}{R \cdot 293K} \quad C_i = 624.094 \frac{\text{mol}}{\text{m}^3}$$

Flux through walls, from Fick's Law (assume vessel walls and ends = 0.5 cm thick)

$$Q_{Xe} := \frac{C_i}{0.5\text{cm}} \cdot D_{Xe_PP} \cdot A_{Xe_v} \quad Q_{Xe} = 2.962 \times 10^{-6} \frac{\text{mol}}{\text{s}}$$

$$\text{In mass terms:} \quad M_{a_Xe} \cdot Q_{Xe} = 0.403 \frac{\text{mg}}{\text{s}} \quad M_{a_Xe} \cdot Q_{Xe} = 12.71 \frac{\text{kg}}{\text{yr}}$$

This does not include leaks, which will likely double the flux into N2. There will need to be cryopumping of the N2 to reclaim Xe, it is not clear whether circulation will also be needed; Xe will likely find its way to cryopanel outside. Assuming a Xe partial pressure of 10^{-8} torr at a cryopanel surface combined with a pumping speed 10% of that for the Xe vessel, we find an Xe partial pressure and mass in the N2 buffer region:

$$P_{Xe_buf} := 10^{-8} \text{ torr} + \frac{2Q_{Xe} \cdot (R \cdot 293K)}{0.1C_{m_tot}} \quad P_{Xe_buf} = 0.365 \text{ torr}$$

$$M_{Xe_buf} := \frac{1\text{m}^3 \cdot P_{Xe_buf} \cdot M_{a_Xe}}{R \cdot 293K} \quad M_{Xe_buf} = 2.715 \text{ gm} \quad \text{Cost}_{Xe} := \frac{10^6 \text{ euro}}{100\text{kg}} \quad \text{Cost}_{Xe} = 10 \frac{\text{euro}}{\text{gm}}$$

This is an inconsequential amount of Xe in the buffer region, regarding dielectric strength and cost, so it does not appear that N2 gas circulation is needed to reduce this to a lower concentration. N2 buffer gas circulation might be desirable for other reasons, however.